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(54) **PROJECTION DISPLAY APPARATUS**

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G02B 27/09 (2006.01)
G02B 27/14 (2006.01)
G02B 26/00 (2006.01)

(52) **U.S. Cl.**

CPC ***G03B 21/28*** (2013.01); ***G02B 26/008*** (2013.01); ***G02B 27/0972*** (2013.01); ***G02B 27/141*** (2013.01)

(58) **Field of Classification Search**

CPC ... G03B 21/28; G02B 27/0972; G02B 27/141
See application file for complete search history.

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(57) **ABSTRACT**

The projection display apparatus according to the present disclosure includes: a light source part; a color separating mirror that separates light emitted from the light source part into a first color light and a second color light; a first light modulation element that modulates the first color light; a second light modulation element that modulates the second color light; a color combining prism unit that combines the first color light modulated by the first light modulation element and the second color light modulated by the second light modulation element; and a projection unit that projects combined light emitted from the color combining prism unit. The color combining prism unit includes four prisms and has two air gap faces that totally reflect or transmit light depending on the angle of incidence.

19 Claims, 6 Drawing Sheets

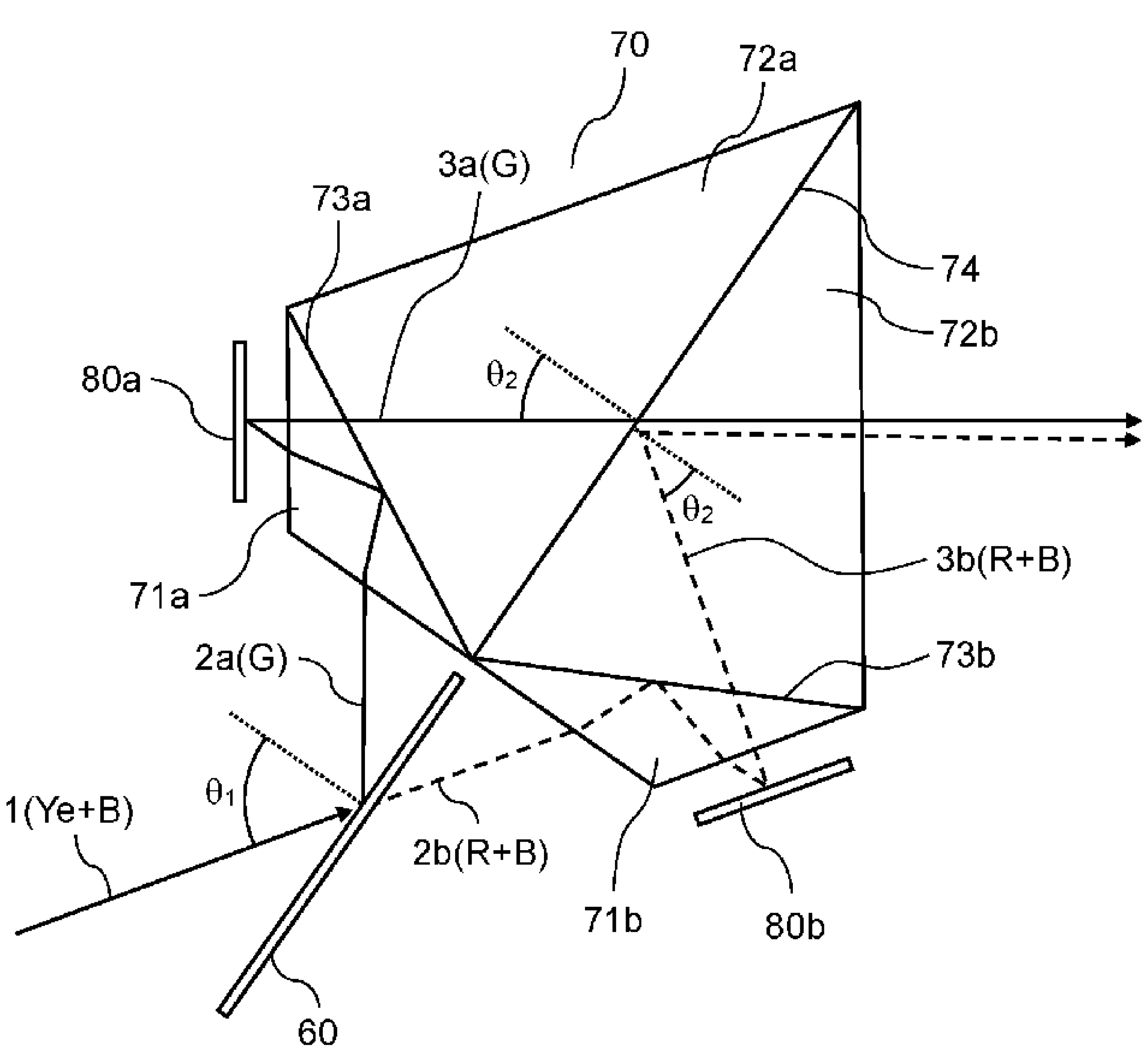

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FIG. 1

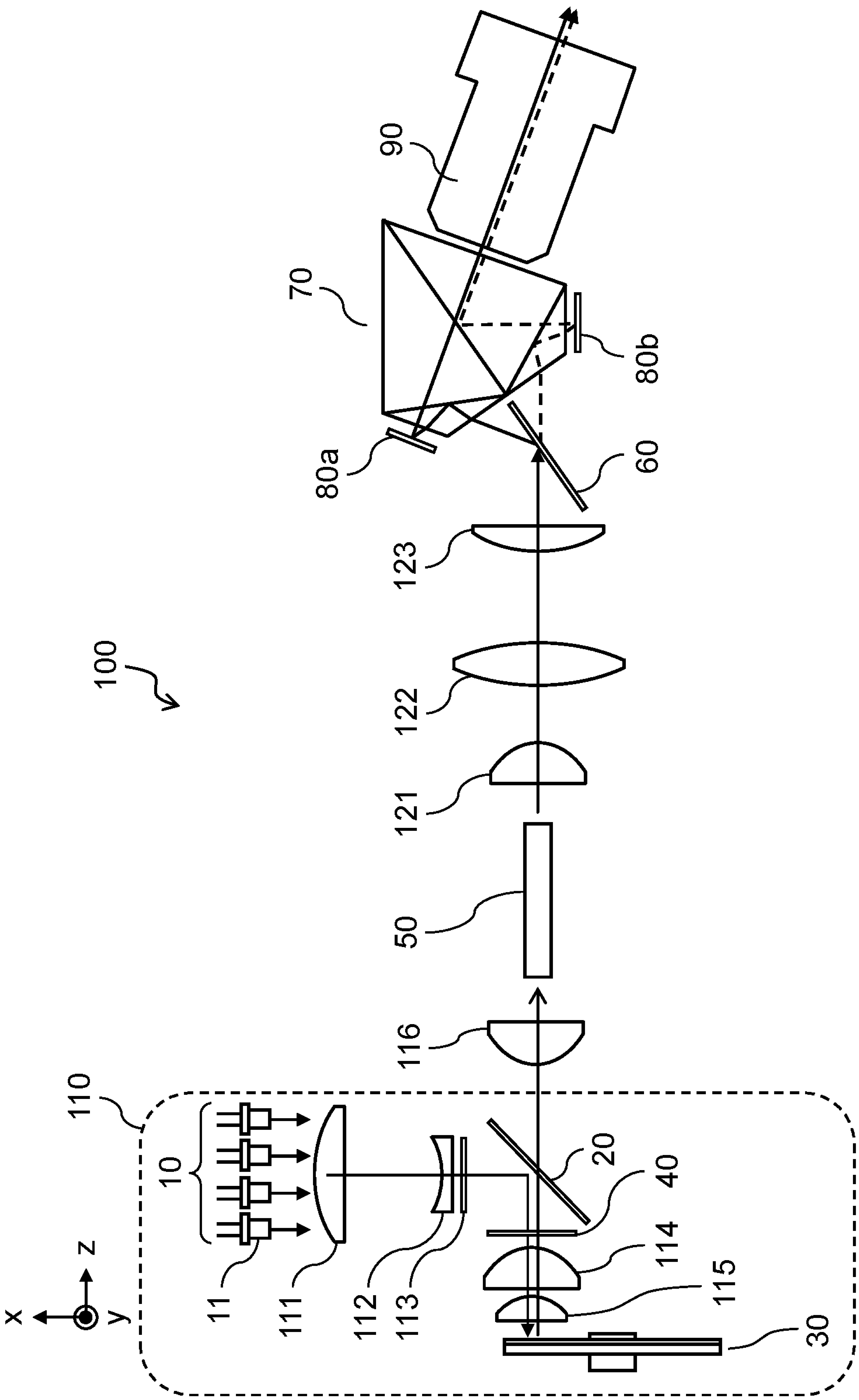

90
70
80b
80a
60
123
122
100
121
50
116
110
10
20
40
114
115
11
111
112
113
30
x
y
z

FIG. 2

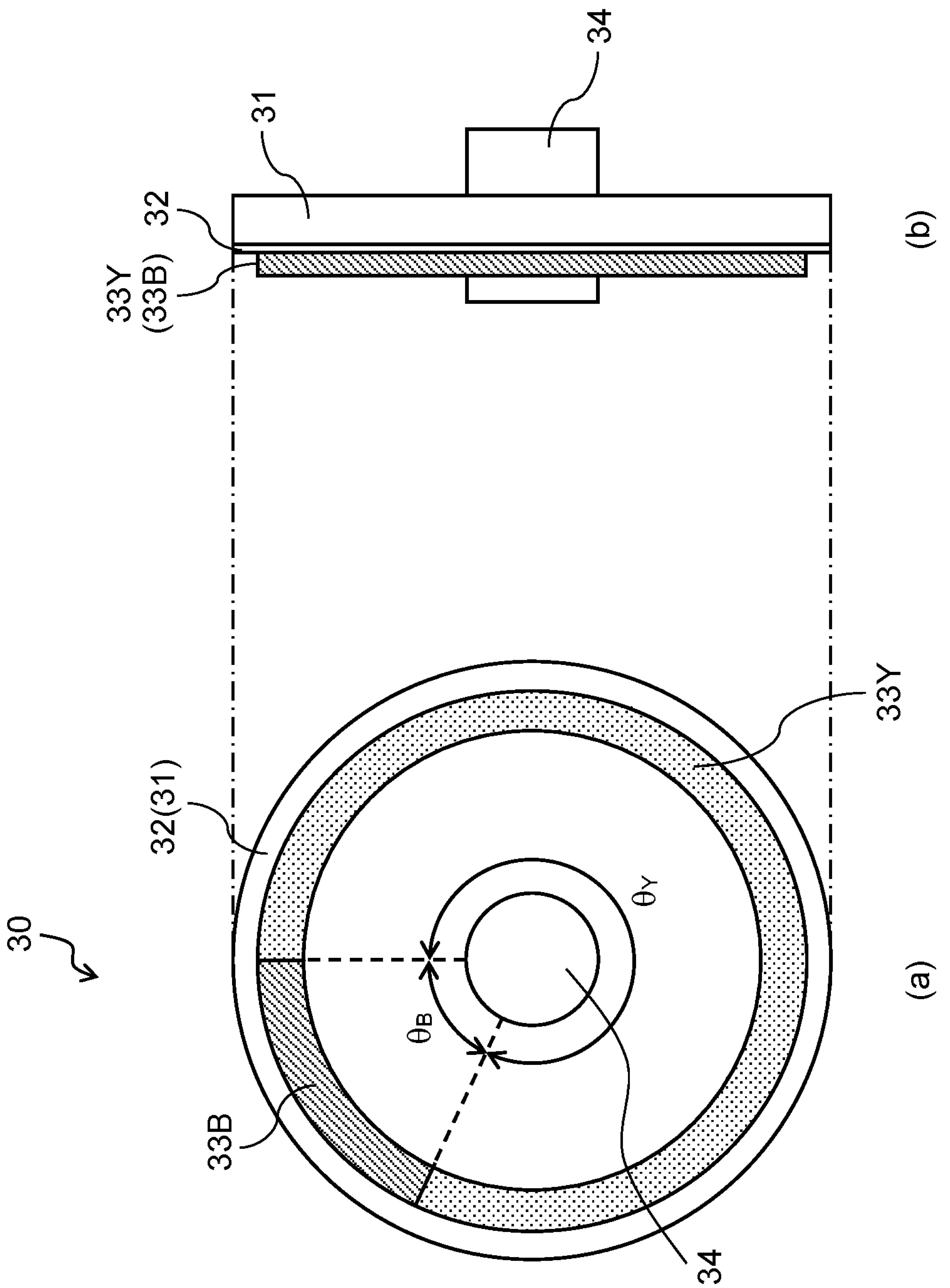


FIG. 3

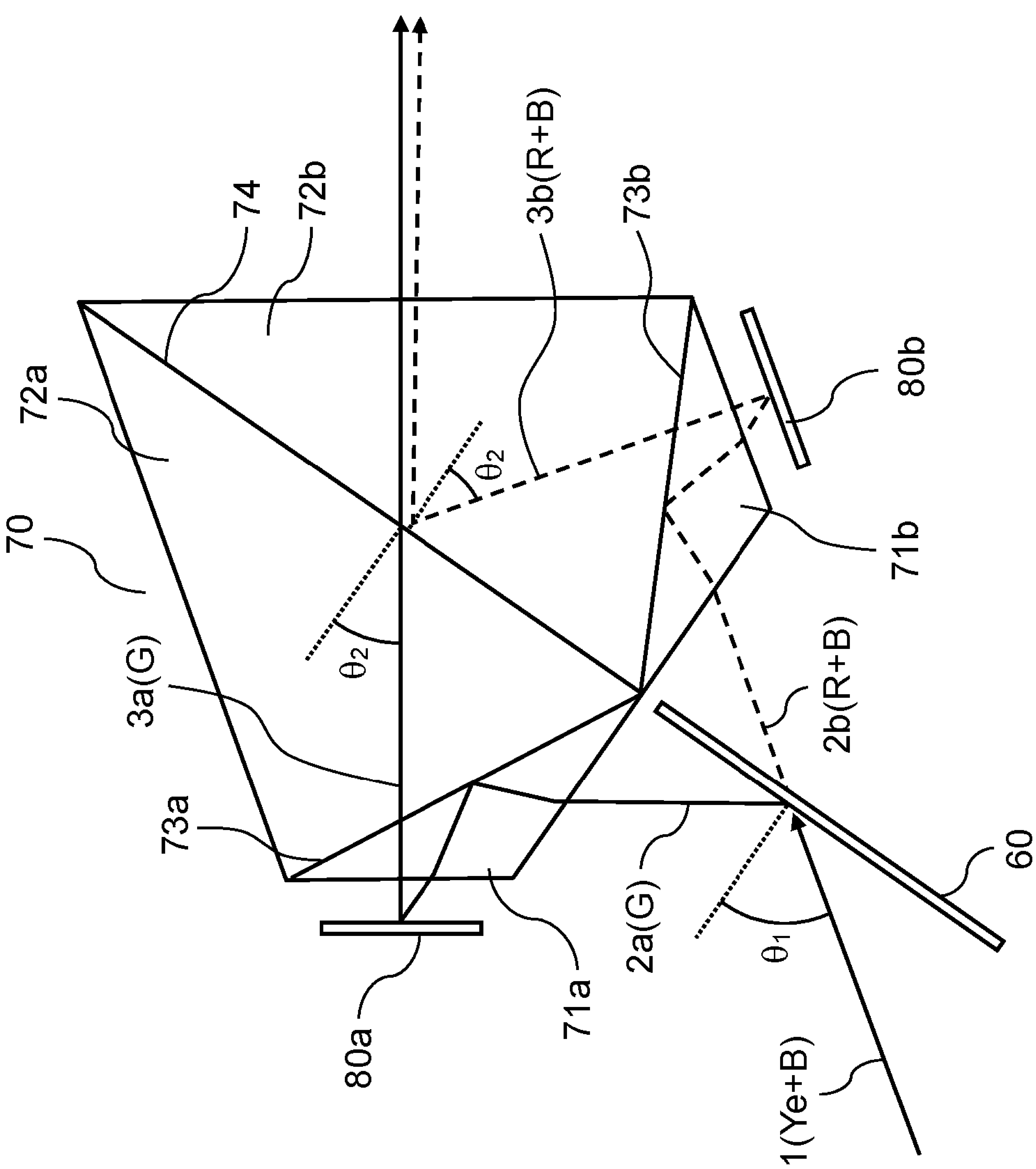

70
72a
74
72b
3b(R+B)
73b
80b
71b
2b(R+B)
60
θ_1
θ_2
θ_2
1(Ye+B)
2a(G)
71a
80a
73a
3a(G)

FIG. 4

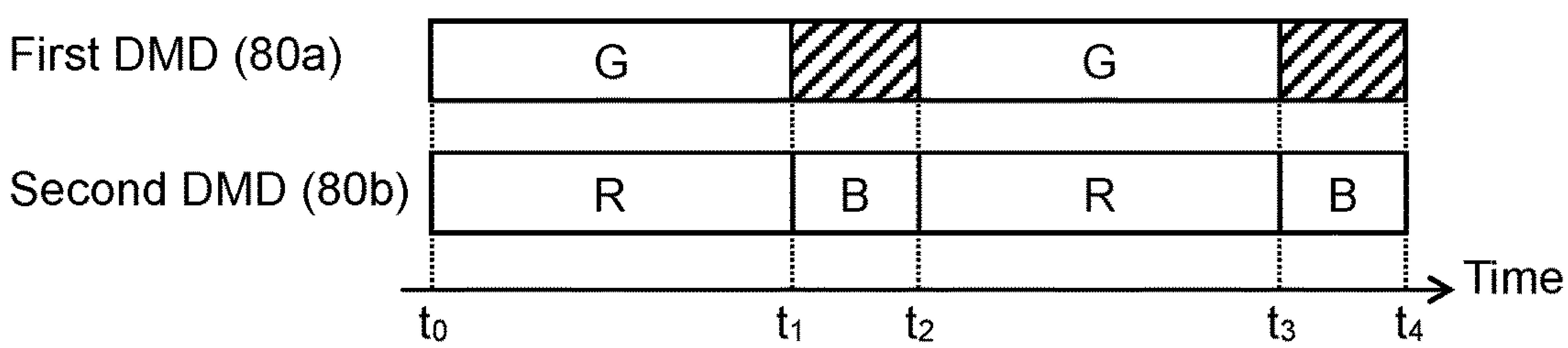
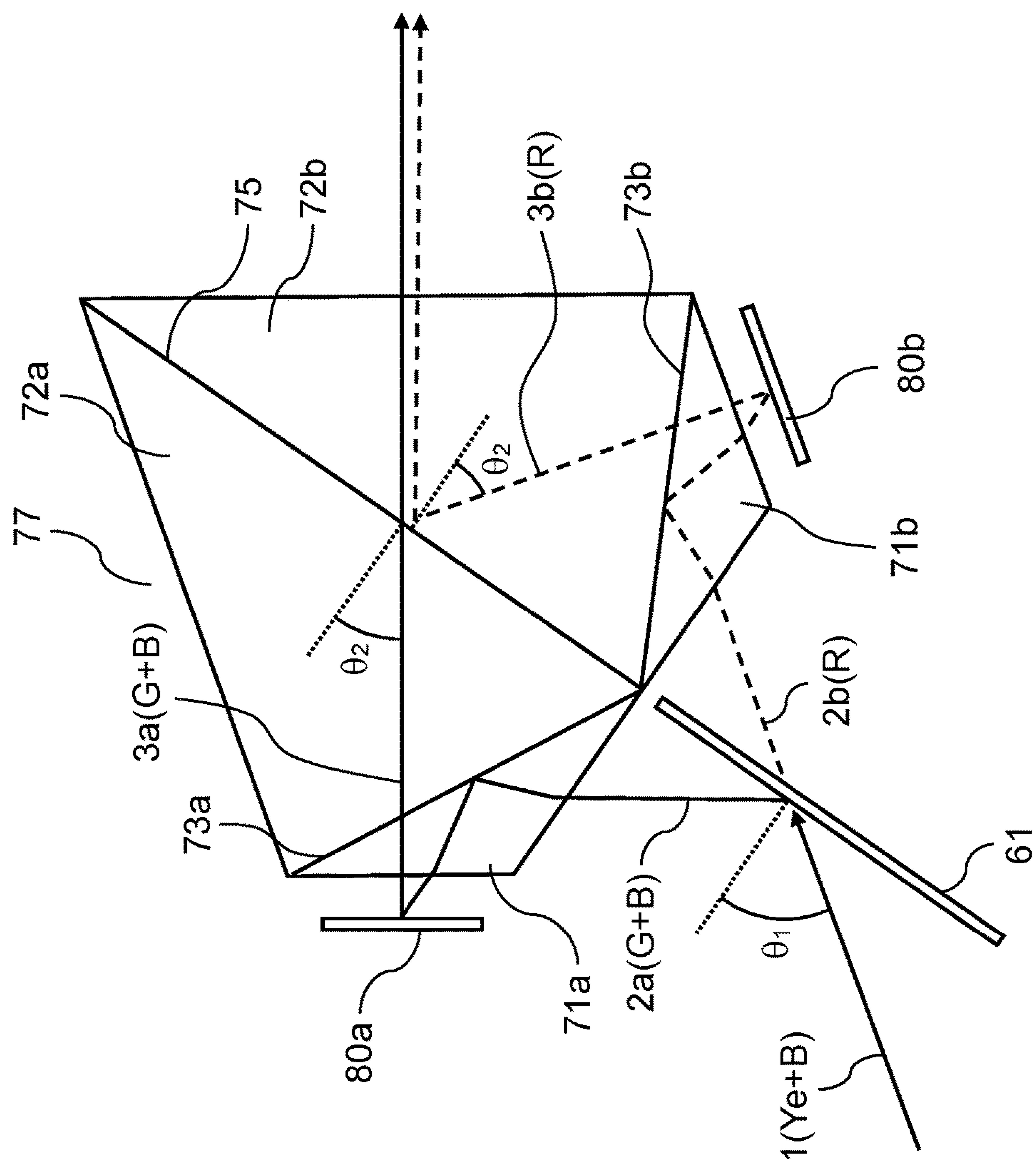
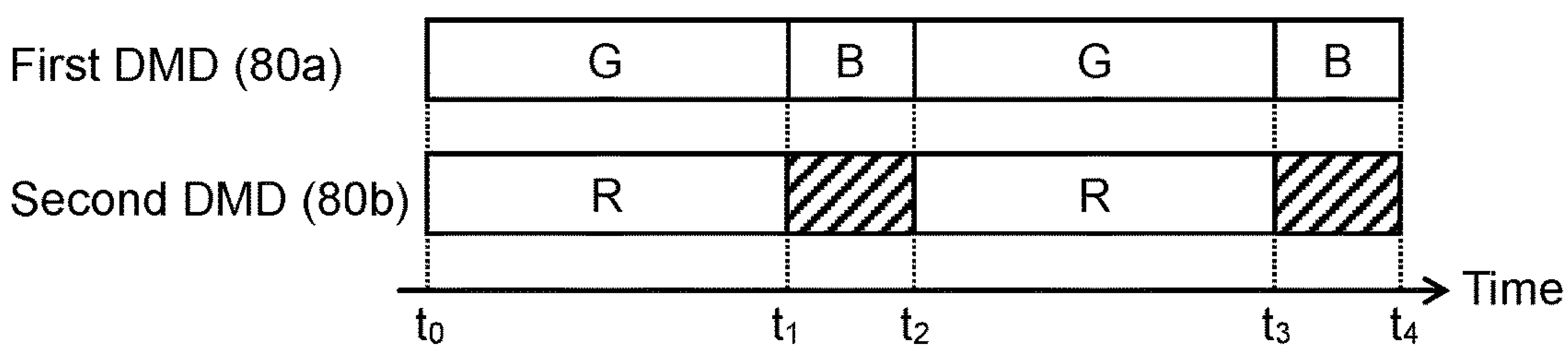


FIG. 5



75
72b
3b(R)
73b
72a
80b
θ_2
77
71b
θ_2
3a(G+B)
2b(R)
73a
61
2a(G+B)
θ_1
80a
71a
1(Ye+B)

FIG. 6



PROJECTION DISPLAY APPARATUS

BACKGROUND

1. Technical Field

The present disclosure relates to a two-plate-type projection display apparatus which displays images using two reflective display elements.

2. Description of the Related Art

Patent Literature (PTL) 1 (Unexamined Japanese Patent Publication No. 2010-097002) discloses a two-plate-type projection device which includes a TIR prism, a dichroic prism, two reflective spatial light modulation elements, and a polarizing element and further includes an optical system that switches the polarization direction of light of each of R, G, B colors by time-division so that high-quality color images can be projected.

CITATION LIST

Patent Literature

PTL 1: Unexamined Japanese Patent Publication No. 2010-097002

SUMMARY

The present disclosure provides a projection display apparatus which has the two-plate-type configuration using two reflective display elements and is capable of displaying bright images without complicated configurations.

The projection display apparatus according to the present disclosure includes: a light source part; a color separating mirror that separates light emitted from the light source part into a first color light and a second color light; a first light modulation element that modulates the first color light; a second light modulation element that modulates the second color light; a color combining prism unit that combines the first color light modulated by the first light modulation element and the second color light modulated by the second light modulation element; and a projection unit that projects combined light emitted from the color combining prism unit. The color combining prism unit includes four prisms and has two air gap faces that totally reflect or transmit light depending on the angle of incidence.

According to the present disclosure, bright projection light is obtained with a simple configuration of the two-plate-type in which two reflective display elements are used.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a projection display apparatus according to the first exemplary embodiment;

FIG. **2** illustrates a phosphor wheel according to the first exemplary embodiment;

FIG. **3** illustrates details of a color separating/combining unit according to the first exemplary embodiment;

FIG. **4** illustrates an operation of a DMD according to the first exemplary embodiment;

FIG. **5** illustrates details of a color separating/combining unit according to the second exemplary embodiment; and

FIG. **6** illustrates an operation of a DMD according to the second exemplary embodiment.

DETAILED DESCRIPTION

Hereinafter, exemplary embodiments will be described in detail with reference to the drawings as necessary. However, there are instances where overly detailed description is omitted. For example, detailed description of well-known matter, overlapping description of substantially identical elements, etc., may be omitted. This is to prevent the subsequent description from becoming unnecessarily redundant, and thus facilitate understanding by a person having ordinary skill in the art.

Note that the accompanying drawings and the subsequent description are provided so that a person having ordinary skill in the art is able to sufficiently understand the present disclosure, and are not intended to limit the scope of the subject matter recited in the claims.

First Exemplary Embodiment

Projection Display Apparatus

Hereinafter, the configuration of a projection display apparatus according to the first exemplary embodiment will be described with reference to FIG. **1** to FIG. **4**. FIG. **1** illustrates an optical configuration of projection display apparatus **100** according to the first exemplary embodiment.

As illustrated in FIG. **1**, projection display apparatus **100** includes: light source unit **10**, dichroic mirror **20**, phosphor wheel **30**, A14 plate **40**, rod integrator **50**, color separating mirror **60**, color combining prism unit **70**, two digital mirror devices (DMDs) (first DMD **80***a* and second DMD **80***b*), and projection unit **90**.

Light source unit **10** includes, for example, a plurality of solid-state light sources such as laser diodes (LDs) and light-emitting diodes (LEDs). In the present exemplary embodiment, laser diodes, particularly, laser diodes **11** which emit blue light, are used as the solid-state light sources.

Light emitted from light source unit **10** is blue light having a wavelength of 455 nm and is used as imaging light and also used as excitation light for exciting a phosphor in phosphor wheel **30**. Note that the wavelength of the blue light which light source unit **10** emits is not limited to 455 nm and may be, for example, a wavelength of 440 nm to 460 nm.

The blue light emitted from light source unit **10** passes through lens **111**, lens **112**, and diffusion plate **113** and enters dichroic mirror **20**. Dichroic mirror **20** reflects the blue light. The blue light reflected by dichroic mirror **20** is collected by lenses **114** and **115** and excites the phosphor in phosphor wheel **30** so that the phosphor emits light.

The light emitted from light source unit **10** is s-polarized blue light, and dichroic mirror **20** reflects the s-polarized blue light and transmits yellow luminescent light emitted by phosphor wheel **30** and p-polarized blue light reflected by phosphor wheel **30**. Thus, dichroic mirror **20** reflects the s-polarized blue light and transmits the p-polarized blue light and the non-polarized yellow luminescent light.

Light source unit **10** including laser diodes **11**, lens **111**, lens **112**, diffusion plate **113**, dichroic mirror **20**, lenses **114** and **115**, phosphor wheel **30**, and $\lambda/4$ plate **40** form light source part **110**.

As illustrated in FIG. **2**, phosphor wheel **30** includes: substrate **31**; reflection coating **32** formed on substrate **31**; yellow phosphor coating **33**Y and diffusion layer **33**B formed on reflection coating **32** by coating in a circular annular shape; and motor **34** for rotating substrate **31**. In FIG. **2**, (a) illustrates phosphor wheel viewed in the negative direction of the z axis in FIG. **1**, and (b) illustrates phosphor wheel viewed along the y axis in FIG. **1**.

Yellow phosphor coating **33**Y can be produced, for example, by applying a mixture of powdery ceramic phosphor with an adhesive (silicone resin) to the substrate and curing the mixture at high temperature. The ceramic phosphor to be used for yellow phosphor coating **33**Y is, for example, an YAG phosphor or a LAG phosphor which has a cerium-activated garnet structure.

Phosphor wheel **30** includes two segments in a circumferential direction, as illustrated in (a) in FIG. **2**. A first segment (angle region θ_Y) is for generating yellow light Ye. A second segment (angle region θ_B) is for generating blue light B.

Yellow phosphor coating **33**Y includes phosphor Y which emits yellow luminescent light according to the blue light (excitation light) emitted from light source unit **10**. Note that yellow phosphor coating **33**Y is a region that is irradiated with the blue light (excitation light) during rotation of phosphor wheel **30**. In other words, lens **115** collects the blue light onto yellow phosphor coating **33**Y.

Diffusion layer **33**B diffuses the blue light (imaging light) emitted from light source unit **10** while maintaining the polarization of the blue light. For example, diffusion layer **33**B has a refractive diffusion structure.

Returning to FIG. **1**, when the blue light (excitation light) irradiates the first segment (angle region θ_Y) of the phosphor wheel, luminescent yellow light Ye is collimated by lens **114** and lens **115** and passes through dichroic mirror **20**, and the light emitted from dichroic mirror **20** is collected into rod integrator **50** by lens **116**.

When the blue light (imaging light) irradiates the second segment (angle region θ_B) of the phosphor wheel, the s-polarized blue light is converted into circularly polarized light by passing through λ/4 plate **40**, is reflected by reflection coating **32** and diffused on diffusion layer **33**B in phosphor wheel **30**, and is converted into p-polarized light by passing through λ/4 plate **40** again. Blue light B that has been converted into the p-polarized light passes through dichroic mirror **20** and is collected into rod integrator **50** by lens **116**.

Thus, phosphor wheel **30** generates yellow light Ye by allowing the first segment (angle region θ_Y) to be irradiated with the blue light which serves as excitation light, and generates blue light B which serves as imaging light by allowing the second segment (angle region θ_B) to be irradiated with the blue light. Furthermore, phosphor wheel **30** rotates to generate yellow light Ye and blue light B (imaging light) by time-division. Thus, yellow light Ye and blue light B (imaging light) enter rod integrator **50** by time-division, thus entering rod integrator **50** as white light in terms of time average.

Rod integrator **50** is a solid rod formed of a transparent member such as glass. Rod integrator **50** homogenizes the white light (yellow light Ye+blue light B) generated by phosphor wheel **30**. Note that rod integrator **50** may be a solid rod having a mirror surface as an inner wall. Rod integrator **50** is one example of a light-homogenizing element.

Lens **121**, lens **122**, and lens **123** are a relay optical system that guides the light homogenized by rod integrator **50** to DMD **80***a* and DMD **80***b* via color separating mirror **60**.

Next, the details of a color separating/combining unit will be described with reference to FIG. **3**. The color separating/combining unit illustrated in FIG. **3** includes color separating mirror **60**, color combining prism unit **70**, first DMD **80***a*, and second DMD **80***b*. In FIG. **3**, the solid lines and the dashed lines indicate only rays (reference rays) passing through the center of an optical axis.

Color separating mirror **60** is a dichroic mirror that separates the white light emitted from rod integrator **50** between an optical path leading to first DMD **80***a* and an optical path leading to second DMD **80***b*. In the present exemplary embodiment, color separating mirror **60** reflects green light G and transmits red light R and blue light B. Specifically, as illustrated in FIG. **3**, color separating mirror **60** separates white illuminating light **1** (Ye+B) into first illuminating light **2***a* (G) and second illuminating light **2***b* (R+B). First illuminating light **2***a* (G) is one example of the first color light, and second illuminating light **2***b* (R+B) is one example of the second color light.

Color combining prism unit **70** is an integrated prism unit in which four prisms, namely, prism **71***a*, prism **71***b*, prism **72***a*, and prism **72***b*, are bonded to one another via first air gap face **73***a*, second air gap face **73***b*, and dichroic coating **74**, as illustrated in FIG. **3**.

In FIG. **3**, the four prisms, i.e., prism **71***a*, prism **71***b*, prism **72***a*, and prism **72***b*, included in color combining prism unit **70** are in the shape of a triangular prism having a certain thickness in the depth direction of the figure (a direction perpendicular to the figure). Two of the four prisms included in color combining prism unit **70**, specifically, prism **71***a* and prism **71***b*, are shaped and arranged plane-symmetric about a plane including dichroic coating **74** as a plane of symmetry. Prism **72***a* and prism **72***b* are shaped and arranged plane-symmetric about a plane including dichroic coating **74** as a plane of symmetry. More specifically, two of the four prisms included in color combining prism unit **70**, specifically, prism **72***a* and prism **72***b*, are arranged opposite to each other across dichroic coating **74**.

In the present exemplary embodiment, prism **71***a*, prism **71***b*, prism **72***a*, and prism **72***b* are the same glass material that is BK7. The glass material may be any available material for optical use and can be changed according to the optical design.

First air gap face **73***a* and second air gap face **73***b* are provided with tiny clearance (air layer) such that when the angle of incidence of a ray with respect to the air gap face exceeds the critical angle, the ray is totally reflected. On the other hand, first air gap face **73***a* and second air gap face **73***b* are bonded with an adhesive in a region where no light enters. The air gap clearance may be, for example, approximately 2 μm to 10 μm.

In the present exemplary embodiment, dichroic coating **74** reflects red light R and blue light B and transmits green light G. Dichroic coating **74** is a coating of a surface of prism **72***a* or prism **72***b*, and prism **72***a* and prism **72***b* are optically in contact via an adhesive. Prism **72***a* and prism **72***b* may be joined by optical contact bonding. Color combining prism unit **70** is a prism that has the functions of both a TIR prism and a dichroic prism which are commonly used in a projection display apparatus using a DMD.

First DMD **80***a* and second DMD **80***b* modulate the light homogenized by rod integrator **50**. Specifically, each of first DMD **80***a* and second DMD **80***b* is a reflective display element including a plurality of micromirrors that are movable. Each of the micromirrors is basically equivalent to one pixel. First DMD **80***a* and second DMD **80***b* switch between ON light (projection light) and OFF light (unnecessary light) by the modulation operation of changing the angle of each of the micromirrors according to an image signal. First DMD **80***a* is one example of a first light modulation element, and second DMD **80***b* is one example of a second light modulation element.

First illuminating light **2***a* (G) reflected by color separating mirror **60** enters prism **71***a*, is totally reflected by first air gap face **73***a*, and irradiates first DMD **80***a*. The shape of the prism is determined such that the angle of incidence of first illuminating light **2***a* (G) with respect to first air gap face **73***a* exceeds the critical angle. In the present exemplary embodiment, the critical angle is calculated to be 41.18 degrees because the glass material is BK7 and the refractive index is 1.5187 (at a wavelength of 546.1 nm). First projection light **3***a* (G) converted by first DMD **80***a* into ON light enters prism **71***a* again, passes through first air gap face **73***a*, and passes through dichroic coating **74**.

The shape of the prism is determined such that the angle of incidence of first projection light **3***a* (G) with respect to first air gap face **73***a* is less than the critical angle. The reference ray of first projection light **3***a* (G) emitted from first DMD **80***a* is perpendicular to first DMD **80***a*. In other words, the angle of incidence of the reference ray of first illuminating light **2***a* (G) with respect to first DMD **80***a* is adjusted so that the reference ray of first projection light **3***a* (G) becomes perpendicular to first DMD **80***a*. In the present exemplary embodiment, the angle of incidence of the reference ray of first illuminating light **2***a* (G) with respect to first DMD **80***a* is 34 degrees.

Second illuminating light **2***b* (R+B) transmitted by color separating mirror **60** enters prism **71***b*, is totally reflected by second air gap face **73***b*, and irradiates second DMD **80***b*. The shape of the prism is determined such that the angle of incidence of second illuminating light **2***b* (R+B) with respect to second air gap face **73***b* exceeds the critical angle. In the present exemplary embodiment, the critical angle is calculated to be 41.18 degrees because the glass material is BK7 and the refractive index is 1.5187 (at a wavelength of 546.1 nm). Second projection light **3***b* (R+B) converted by second DMD **80***b* into ON light enters prism **71***b* again, passes through second air gap face **73***b*, and is reflected by dichroic coating **74**.

The shape of the prism is determined such that the angle of incidence of second projection light **3***b* (R+B) with respect to second air gap face **73***b* is less than the critical angle. The reference ray of second projection light **3***b* (R+B) emitted from second DMD **80***b* is perpendicular to second DMD **80***b*. In other words, the angle of incidence of the reference ray of second illuminating light **2***b* (R+B) with respect to second DMD **80***b* is adjusted so that the reference ray of second projection light **3***b* (R+B) becomes perpendicular to second DMD **80***b*. In the present exemplary embodiment, the angle of incidence of the reference ray of second illuminating light **2***b* (R+B) with respect to second DMD **80***b* is 34 degrees.

Here, as illustrated in FIG. **3**, suppose the angle of incidence of white illuminating light **1** (Ye+B) with respect to color separating mirror **60** (the angle formed between the surface normal and the reference ray) is denoted as angle of incidence θ_1, and the angle of incidence of the reference ray of each of first projection light **3***a* (G) and second projection light **3***b* (R+B) with respect to dichroic coating **74** of color combining prism unit **70** (the angle formed between the surface normal and the reference ray) is denoted as angle of incidence θ_2; angle of incidence θ_1 and angle of incidence θ_2 are preferably set to the smallest possible degree. Specifically, angle of incidence $\theta_1 \leq 60$ degrees and angle of incidence $\theta_2 \leq 45$ degrees are preferred. In the present exemplary embodiment, angle of incidence $\theta_1 = 55$ degrees and angle of incidence $\theta_2 = 35$ degrees, which satisfy angle of incidence $\theta_1 \leq 60$ degrees and angle of incidence $\theta_2 \leq 45$ degrees. With such angle settings, the coating design for color separating mirror **60** and the coating design for dichroic coating **74** are facilitated, allowing an increase in the efficiency of color separation and combination.

At the same time, angle of incidence $\theta_1 >$ angle of incidence θ_2 is preferred. In the present exemplary embodiment, angle of incidence $\theta_1 = 55$ degrees and angle of incidence $\theta_2 = 35$ degrees, which satisfy angle of incidence $\theta_1 >$ angle of incidence θ_2. With such angle settings, the coating design for color separating mirror **60** and the coating design for dichroic coating **74** are facilitated, allowing an increase in the efficiency of color separation and combination.

With this, first illuminating light **2***a* (G) and second illuminating light **2***b* (R+B) resulting from separation of white illuminating light **1** (Ye+B) by color separating mirror **60** are combined by color combining prism unit **70** and then are emitted as combined light.

Note that color separating mirror **60** is configured to reflect green light G and transmit red light R and blue light B in the present exemplary embodiment, but may be configured to reflect red light R and blue light B and transmit green light G. Furthermore, dichroic coating **74** is configured to reflect red light R and blue light B and transmit green light G in the present exemplary embodiment, but may be configured to reflect green light G and transmit red light R and blue light B.

Next, the principle of color image display using first DMD **80***a* and second DMD **80***b* will be described with reference to FIG. **4**.

First DMD **80***a* represents the gradation of green light G by the modulation operation of each of the micromirrors on the basis of a green (G) image signal. Specifically, the gradation of green light G is represented between time t_0 and time t_1, no images are displayed between time t_1 and time t_2, the gradation of green light G is represented between time t_2 and time t_3, and no images are displayed between time t_3 and time t_4. Although not illustrated in the drawings, the same or similar process is repeated after time t_4 as well on the basis of the image signal.

Second DMD **80***b* represents the gradations of red light R and blue light B by the modulation operation of each of the micromirrors on the basis of a red (R) image signal and a blue (B) image signal. Specifically, the gradation of red light R is represented between time t_0 and time t_1, the gradation of blue light B is represented between time t_1 and time t_2, the gradation of red light R is represented between time t_2 and time t_3, and the gradation of blue light B is represented between time t_3 and time t_4. Although not illustrated in the drawings, the same or similar process is repeated after time t_4 as well on the basis of the image signal.

Note that the time interval between time t_0 and time t_2 (or time t_2 and time t_4) may be set as one frame of the images, or may be set as one sub-frame where three sub-frames form one frame of the images.

Here, time t_0 to time t_1 and time t_2 to time t_3 correspond to time for which the first segment (angle region θ_B) of phosphor wheel **30** is irradiated with blue light as the excitation light. Specifically, between time t_0 and time t_1 and between time t_2 and time t_3, phosphor wheel **30** generates yellow light Ye, color separating mirror **60** separates the light into green light G and red light R, first DMD **80***a* is illuminated with green light G, and second DMD **80***b* is illuminated with red light R.

Here, time t_1 to time t_2 and time t_3 to time t_4 correspond to time for which the second segment (angle region θ_B) of phosphor wheel **30** is irradiated with blue light as the imaging light. Specifically, between time t_1 and time t_2 and between time t_3 and time t_4, blue light B is reflected by phosphor wheel **30** and then separated by color separating mirror **60** to travel in an optical path leading to second DMD **80***b* so that second DMD **80***b* is illuminated with blue light B.

Operations and Advantageous Effects

In the first exemplary embodiment, in the two-plate-type configuration using two DMDs, the color combining prism unit including four prisms, two air gap faces, and one dichroic coating enables implementation of a small, simple optical system. Furthermore, by setting the angle of incidence of the reference ray with respect to dichroic coating **74** less than the angle of incidence of the reference ray with respect to color separating mirror **60**, it is possible to increase the efficiency of color separation and combination, resulting in a bright projection display apparatus.

Second Exemplary Embodiment

In the first exemplary embodiment, color separating mirror **60** is configured to reflect green light G and transmit red light R and blue light B. Furthermore, in the first exemplary embodiment, dichroic coating **74** is configured to reflect red light R and blue light B and transmit green light G. Specifically, color separating mirror **60** is configured to separate white illuminating light **1** (Ye+B) into first illuminating light **2***a* (G) and second illuminating light **2***b* (R+B), and dichroic coating **74** of color combining prism unit **70** is configured to combine first projection light **3***a* (G) and second projection light **3***b* (R+B).

In the second exemplary embodiment, as illustrated in FIG. **5**, color separating mirror **61** is provided instead of color separating mirror **60**, and color separating mirror **61** reflects green light G and blue light B and transmits red light R. Furthermore, color combining prism unit **77** includes dichroic coating **75** instead of dichroic coating **74**, and dichroic coating **75** transmits green light G and blue light B and reflects red light R. Specifically, color separating mirror **61** separates white illuminating light **1** (Ye+B) into first illuminating light **2***a* (G+B) and second illuminating light **2***b* (R), and dichroic coating **75** of color combining prism unit **77** combines first projection light **3***a* (G+B) and second projection light **3***b* (R). Thus, the color separating/combining unit illustrated in FIG. **5** includes color separating mirror **61**, color combining prism unit **77**, first DMD **80***a*, and second DMD **80***b*. First illuminating light **2***a* (G+B) is one example of the first color light, and second illuminating light **2***b* (R) is one example of the second color light. Elements that are the same as or similar to those in the first exemplary embodiment are assigned the same reference signs, and description thereof will be omitted.

As illustrated in FIG. **5**, first illuminating light **2***a* (G+B) reflected by color separating mirror **61** enters prism **71***a*, is totally reflected by first air gap face **73***a*, and irradiates first DMD **80***a*. First projection light **3***a* (G+B) converted by first DMD **80***a* into ON light enters prism **71***a* again, passes through first air gap face **73***a*, and passes through dichroic coating **75**. Second illuminating light **2***b* (R) transmitted by color separating mirror **61** enters prism **71***b*, is totally reflected by second air gap face **73***b*, and irradiates second DMD **80***b*. Second projection light **3***b* (R) converted by second DMD **80***b* into ON light enters prism **71***b* again, passes through second air gap face **73***b*, and is reflected by dichroic coating **75**.

The angle of incidence of first illuminating light **2***a* (G+B) with respect to first air gap face **73***a* and first DMD **80***a* and the angle of incidence of first projection light **3***a* (G+B) with respect to first air gap face **73***a* are the same as or similar to those in the first exemplary embodiment. Likewise, the angle of incidence of second illuminating light **2***b* (R) with respect to second air gap face **73***b* and second DMD **80***b* and the angle of incidence of second projection light **3***b* (R) with respect to second air gap face **73***b* are the same as or similar to those in the first exemplary embodiment.

Furthermore, as illustrated in FIG. **5**, angle of incidence θ_1 of white illuminating light **1** (Ye+B) with respect to color separating mirror **61**, angle of incidence θ_2 of the reference ray of each of first projection light **3***a* (G+B) and second projection light **3***b* (R) with respect to dichroic coating **75** of color combining prism unit **77**, and the relationship between angle of incidence θ_1 and angle of incidence θ_2 are the same as or similar to those in the first exemplary embodiment.

Note that color separating mirror **61** is configured to reflect green light G and blue light B and transmit red light R in the present exemplary embodiment, but may be configured to reflect red light R and transmit green light G and blue light B. Furthermore, dichroic coating **75** is configured to reflect red light R and transmit green light G and blue light B in the present exemplary embodiment, but may be configured to reflect green light G and blue light B and transmit red light R.

The principle of color image display in the second exemplary embodiment will be described with reference to FIG. **6**.

First DMD **80***a* represents the gradations of green light G and blue light B by the modulation operation of each of the micromirrors on the basis of the green (G) image signal and the blue (B) image signal. Specifically, the gradation of green light G is represented between time t_0 and t_1, the gradation of blue light B is represented between time t_1 and t_2, the gradation of green light G is represented between time t_2 and t_3, and the gradation of blue light B is represented between time t_3 and t_4. Although not illustrated in the drawings, the same or similar process is repeated after time t_4 as well on the basis of the image signal.

Second DMD **80***b* represents the gradation of red light R by the modulation operation of each of the micromirrors on the basis of the red (R) image signal. Specifically, the gradation of red light R is represented between time t_0 and t_1, no images are displayed between time t_1 and t_2, the gradation of red light R is represented between time t_2 and t_3, and no images are displayed between time t_3 and t_4. Although not illustrated in the drawings, the same or similar process is repeated after time t_4 as well on the basis of the image signal.

Here, as in the case of the first exemplary embodiment, time t_0 to time t_1 and time t_2 to time t_3 correspond to time for which the first segment (angle region θ_Y) of phosphor wheel **30** is irradiated with blue light as the excitation light, and time t_1 to time t_2 and time t_3 to time t_4 correspond to time for which the second segment (angle region θ_B) of phosphor wheel **30** is irradiated with blue light as the imaging light. In the second exemplary embodiment, between time t_1 and time t_2 and between time t_3 and time t_4, blue light B reflected by phosphor wheel **30** is separated by color separating mirror **61** to travel in an optical path leading to first DMD **80***a* and illuminates first DMD **80***a*.

Also in the case where the color separating/combining unit is configured using color combining prism unit **77** including color separating mirror **61** and dichroic coating **75** as in the second exemplary embodiment, the same or similar advantageous effects as in the first exemplary embodiment are produced.

Other Exemplary Embodiments

The first and second exemplary embodiments have been described above by way of example of techniques disclosed in the present application. The techniques according to the present disclosure, however, are not limited to the foregoing exemplary embodiments, and can also be applied to exemplary embodiments obtained by carrying out modification, substitution, addition, omission, etc. Furthermore, it is also possible to obtain a new embodiment by combining respective structural elements described in the first and second exemplary embodiments. In view of this, other exemplary embodiments will be given below as examples.

Although the blue light serving as the imaging light is produced through the diffusion on diffusion layer **33**B and the reflection on reflection coating **32** in phosphor wheel **30** in the first and second exemplary embodiments, exemplary embodiments are not limited to these exemplary embodiments. Phosphor wheel **30** may have an opening in the portion where diffusion layer **33**B is formed, allowing the blue light entering the second segment (angle region θ_B) of the phosphor wheel to pass and be reflected by a mirror to be guided to dichroic mirror **20** again so as to be reflected by dichroic mirror **20** and thus guided to lens **116**. This also can result in white light that includes blue light (imaging light) and yellow light by time-division.

Although the light modulation element is exemplified by first DMD **80***a* and second DMD **80***b* in the first and second exemplary embodiments, exemplary embodiments are not limited to these exemplary embodiments. The light modulation element may be a reflective liquid-crystal panel.

Note that the above exemplary embodiments are for providing examples of the techniques of the present disclosure, and thus various modifications, substitutions, additions, omissions, etc., are possible in the scope of the claims and equivalent scope thereof.

INDUSTRIAL APPLICABILITY

The present disclosure can be applied to a projection display apparatus such as a projector.

What is claimed is:

1. A projection display apparatus comprising:
- a light source part;
- a color separating mirror that separates light emitted from the light source part into a first color light and a second color light;
- a first light modulation element that modulates the first color light;
- a second light modulation element that modulates the second color light;
- a color combining prism unit that combines the first color light modulated by the first light modulation element and the second color light modulated by the second light modulation element; and
- a projection unit that projects combined light emitted from the color combining prism unit, wherein
- the color combining prism unit includes a first prism, a second prism, a third prism and a fourth prism, the third and fourth prisms having a dichroic coating located therebetween,
- the color combining prism unit has two air gap faces that totally reflect the first and second color lights before incidence on the first and second light modulation elements, respectively, and transmit the modulated first and second color lights after modulation by the first and second light modulation elements, respectively,
- one of the two air gap faces is formed by a surface of the first prism and a surface of the third prism, and
- another of the two air gap faces is formed by a surface of the second prism and a surface of the fourth prism.

2. The projection display apparatus according to claim **1**, wherein
- the third and fourth prisms included in the color combining prism unit are arranged opposite to each other across the dichroic coating, and an angle of incidence of a reference ray with respect to the dichroic coating is 45 degrees or less.

3. The projection display apparatus according to claim **1**, wherein
- the third and fourth prisms included in the color combining prism unit are arranged opposite to each other across the dichroic coating, and an angle of incidence of a reference ray with respect to the dichroic coating is less than an angle of incidence of the reference ray with respect to the color separating mirror.

4. The projection display apparatus according to claim **1**, wherein
- the third and fourth prisms included in the color combining prism unit are arranged opposite to each other across the dichroic coating, and the color combining prism unit has a shape of plane symmetry about the dichroic coating as a plane of symmetry.

5. The projection display apparatus according to claim **1**, wherein
- the third and fourth prisms included in the color combining prism unit are arranged opposite to each other across the dichroic coating, and the dichroic coating transmits the first color light modulated by the first light modulation element and reflects the second color light modulated by the second light modulation element to allow the color combining prism unit to combine the colors of the first color light and the second color light.

6. The projection display apparatus according to claim **1**, wherein
- the light emitted from the light source part includes blue light and yellow light by time-division.

7. The projection display apparatus according to claim **1**, wherein
- each of the first and the second light modulation elements is reflection-type light modulation element.

8. The projection display apparatus according to claim **1**, wherein
- the first and the second color lights configure three colors including red light, green light and blue light, and
- the first light modulation element modulates the first light color which includes two of the red light, the green light and the blue light.

9. The projection display apparatus according to claim **1**, wherein
- the one of the two air gap faces is formed with just air between the surface of the first prism and the surface of the third prism, and
- the other of the two air gap faces is formed with just air between the surface of the second prism and the surface of the fourth prism.

10. The projection display apparatus according to claim **1**, wherein
- the surface of the first prism and the surface of the third prism are parallel to each other, and
- the surface of the second prism and the surface of the fourth prism are parallel to each other.

11. The projection display apparatus according to claim **1**, wherein
- the color combining prism unit consists of the first prism, the second prism, the third prism and the fourth prism.

12. A projection display apparatus comprising:
- a light source part;

a color separating mirror that separates light emitted from the light source part into a first color light and a second color light;

a first light modulation element that modulates the first color light;

a second light modulation element that modulates the second color light;

a color combining prism unit that combines the first color light modulated by the first light modulation element and the second color light modulated by the second light modulation element; and

a projection unit that projects combined light emitted from the color combining prism unit, wherein

the color combining prism unit includes a first prism, a second prism, a third prism and a fourth prism, the third and fourth prisms having a dichroic coating located therebetween,

the color combining prism unit has two air gap faces that totally reflect the first color light and the second color light which are separated by the color separating mirror,

one of the two air gap faces is formed by a surface of the first prism and a surface of the third prism, and

another of the two air gap faces is formed by a surface of the second prism and a surface of the fourth prism.

13. The projection display apparatus according to claim **12**, wherein

the one of the two air gap faces is formed with just air between the surface of the first prism and the surface of the third prism, and

the other of the two air gap faces is formed with just air between the surface of the second prism and the surface of the fourth prism.

14. The projection display apparatus according to claim **12**, wherein

the surface of the first prism and the surface of the third prism are parallel to each other, and

the surface of the second prism and the surface of the fourth prism are parallel to each other.

15. The projection display apparatus according to claim **12**, wherein

the color combining prism unit consists of the first prism, the second prism, the third prism and the fourth prism.

16. A projection display apparatus comprising:

a light source part;

a color separating mirror that separates light emitted from the light source part into a first color light and a second color light;

a first light modulation element that modulates the first color light;

a second light modulation element that modulates the second color light;

a color combining prism unit that combines the first color light modulated by the first light modulation element and the second color light modulated by the second light modulation element; and

a projection unit that projects combined light emitted from the color combining prism unit, wherein

the color combining prism unit includes a first prism, a second prism, a third prism and a fourth prism, the third and fourth prisms having a dichroic coating located therebetween,

the first and second color lights are totally reflected by inner surfaces of the first and the second prisms, respectively,

a light emitted from the first prism passes through the dichroic coating,

a light emitted from the second prism is reflected by the dichroic coating,

a surface of the first prism and a surface of the third prism form a first air gap, and

a surface of the second prism and a surface of the fourth prism form a second air gap.

17. The projection display apparatus according to claim **16**, wherein

the one of the two air gap faces is formed with just air between the surface of the first prism and the surface of the third prism, and

the other of the two air gap faces is formed with just air between the surface of the second prism and the surface of the fourth prism.

18. The projection display apparatus according to claim **16**, wherein

the surface of the first prism and the surface of the third prism are parallel to each other, and

the surface of the second prism and the surface of the fourth prism are parallel to each other.

19. The projection display apparatus according to claim **16**, wherein

the color combining prism unit consists of the first prism, the second prism, the third prism and the fourth prism.

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